[Reprinted from the JOURNAL OF THE FRANKLIN INSTITUTE, Sept., 1889.]

RESULTS OF EXPERIMENTS MADE TO DETERMINE THE PERMEABILITY OF CEMENTS AND CEMENT MORTARS.

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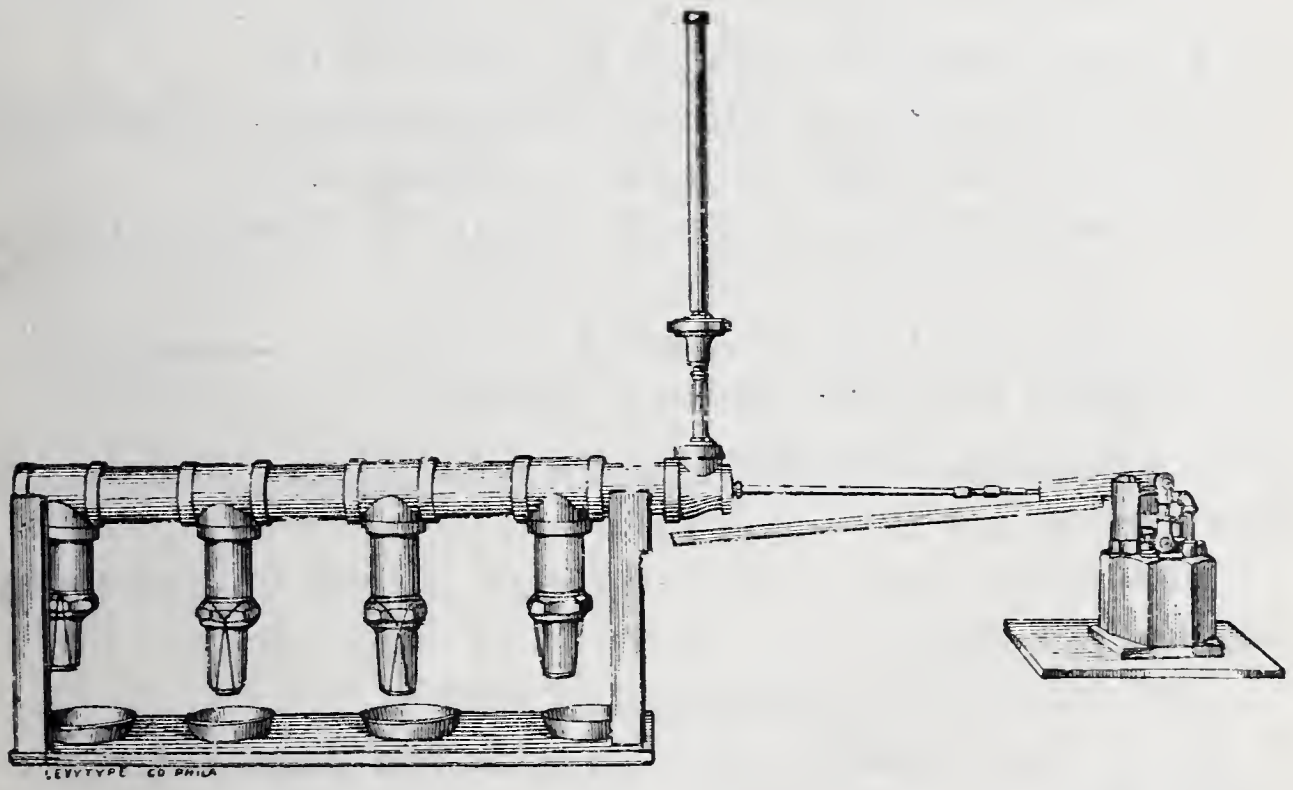
Condensed by L. M. HAUPT.

The apparatus was designed to fulfil the requirements of simplicity, strength, tightness, accuracy, and facility for changing specimens.



It was found to be well adapted to the purpose and consisted of a cylinder composed of wrought-iron three-inch pipes screwed into four cast-iron tees. The far end was closed by a cap, the near end by a tie bushed down to admit the one-fourth-inch feed pipe, on end, and the gauge on top. The specimens to be tested were placed in short six-inch cylinders, three-inch diameter, having a thread cut on the upper end and a perforated cap on the bottom. The hole in the cap was one and one-half inches in diameter. Rubber washers were placed between the caps and samples to be tested, to prevent leakage at the joints. These cylinders containing the specimens were screwed tightly into the tees, and below them

glass beakers were attached by elastic bands to catch the water passing through the cements and mortars.

The water used was first filtered to prevent the choking of the pores by sediment. The pressure was applied by a hand force-pump and maintained throughout the series at 75, 100 and 200 pounds respectively. Four specimens were tested simultaneously.

The accompanying cut will illustrate the simplicity of the apparatus as assembled.

THE SPECIMENS.

Experiments were made on the following brands :

1. Union, furnished by Lesley & Trinkle.
2. Old Newark, by Samuel H. French & Co.
3. Brooks and Shoebridge Portland, Samuel H. French & Co
4. Stettin Portland, Samuel H. French & Co.
5. Anchor Coplay Portland, Samuel H. French & Co.
6. Giant Portland, Lesley & Trinkle.
7. Improved Union, Lesley & Trinkle.
8. Egypt Portland, Lesley & Trinkle.

Each sample was sifted carefully through a sieve having forty meshes to the lineal inch.

The sand was passed through sieves of twenty-five meshes per inch.

The experiments embraced six series :

(*a*) of neat cements after setting seven days.

(*b*) of neat cements after twenty-eight days.

(*c*) of cement mortars, composed of equal parts of cement and sand after seven days.

(*d*) same after twenty-eight days.

(*e*) of cement mortar composed of one part of the former to two of the latter, seven days.

(*f*) same after twenty-eight days.

The specimens were carefully manipulated with just sufficient water to form a thin film when rammed in the mould so as to fill the cylinder to a height of three inches. The samples were allowed to drain for one day, after removing from the water in which they had set, before using.

The following tables give the numerical results of the experiments, showing the amount of percolation in ounces and quarts at the end of each hour under the varying pressures for seven and twenty-eight days, cements and mortars. Where no figures are given, there was no measurable percolation.

TABLE I.—Neat Cements. Seven Days.

No. of Specimen.	Variety.	Pressure, 75 Pounds per Sq. In.				Pressure, 100 Pounds per Sq In				Pressure, 200 Pounds per Sq In.			
		First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.
		ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.
4	B. & S. Eng. Port.,	. . .	. . .	. . .	. . .	. . .	. . .	. .	. . .	. . .	. . .	. . .	. . .
24	Improved Union,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .		.	.	. . .
15	Egypt Port.,	. . .	. . .	. . .	. . .	. . .	. .	. .	.	. . .	. . .	. .	. . .
20	Stettin Port.,	. . .	. .	. . .	. .	. . .	0·028	0·032	0·020	0·059	0·195	0·135	0·129
54	Old Newark Port.	. . .	. . .	. .	. . .	. . .	0·091	0·227	0·106	0·424	0·525	0·498	0·482
22	Union,	0·044	0·143	0·139	0·108	0·094	0·224	0·169	0·162	0·261	0·361	0·358	0·326
11	Anchor (Coplay),	0·203	0·219	0·216	0·212	0·298	0·306	0·299	0·301	0·426	0·442	0·436	0·434
3	Giant Port.,	0·263	0·299	0·326	0·296	0·233	0·173	0·184	0·197	0·562	0·843	1·224	0·875

TABLE II.—Neat Cements. Twenty-eight Days.

No. of Specimen.	Variety.	Pressure, 75 Pounds per Sq. In.				Pressure, 100 Pounds per Sq. In.				Pressure, 200 Pounds per Sq. In.			
		First Hour	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.
		ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs.	ozs	ozs	ozs.	ozs.	ozs.
7	B. & S. Eng. Port.,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. .	. . .	. . .
23	Improved Union,	. . .	. . .	. . .	. . .	. . .	. .	. . .	.	. .	.	. . .	. . .
14	Egypt Port.,	. . .		. . .	. . .	. . .	. . .	. . .	. . .	. .	.	. . .	. . .
41	Stettin Port.,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .		. . .	. . .	. . .
6	Old Newark Port.	. . .	. . .	. . .	.	. . .	. . .	. . .	.	. . .	. . .	.	. . .
21	Union,	. . .	. . .	.	. . .	. . .	. . .	. . .	. .	.	. . .	. . .	. . .
2	Giant Port.,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. .	. .	. . .	. . .
10	Anchor (Coplay),	0·101	0·126	0·103	0·110	0·138	0·186	0·183	0·169	0·416	0·525	0·583	0·518

TABLE III.—Mortars. Seven Days.

Variety.	Ratio Cement to Sand.	Pressure, 75 Pounds per Square Inch.				Pressure, 100 Pounds per Square Inch.				Pressure, 200 Pounds per Square Inch.			
		First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.
		ozs.	*ozs*	*ozs*	*ozs.*	*ozs.*	*ozs*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*
9. Anchor (Coplay),	1 : 1	4·062	5·155	5·533	4·917	5·926	8·493	8·519	7·646	21·239	21·223	19·522	20·694
49. Stettin Port.,	1 : 2	6·819	6·965	6·9[illegible]	6·895	10·693	10·916	10·894	10·834	31·34[illegible]	37·607	34 229	34·392
42. Improved Union,	1 : 1	10·996	11·495	11·411	11·301	17·279	17·593	17·482	17·451	37·699	[illegible]8 635	38·071	38·468
18. Union,	1 : 1	35·753	42·517	43 448	40·573	53·833	59·909	54·112	55·951	77·37[illegible]	109·187	162·941	118·500
17. B & S. Eng. Port.,	1 : 2	50·147	53·254	51·930	51·777	76·004	77·839	77·122	76·988	155·143	156·743	155·583	155·823
35. Giant Port.,	1 : 2	83·056	84 624	84·079	83·919	108·130	109·344	108·912	108·795	137·9[illegible]5	142·606	140·576	140·362
52. Old Newark Port.,	1 : 2	100·294	102·37[illegible]	102·611	101·758	163·684	166·112	165·722	164·17[illegible]	. . .	. . .	. . .	. .
13. Egypt Port.,	1 : 2	138·709	139·183	139·845	139·245	169·847	173·357	172·763	71·999	315·355	362·889	317·635	33[illegible]·426

TABLE IV.—MORTARS. TWENTY-EIGHT DAYS.

VARIETY.	Ratio Cement to Sand.	PRESSURE, 75 POUNDS PER SQUARE INCH.				PRESSURE, 100 POUNDS PER SQUARE INCH.				PRESSURE, 200 POUNDS PER SQUARE INCH.			
		First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.	First Hour.	Second Hour.	Third Hour.	Average per Hour.
		ozs.	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*	*ozs.*
8. Anchor (Coplay),	1 : 1	1·188	0·978	1·061	1·075	1·706	1·829	1·882	1·805	4·308	4·827	4·743	4·626
16. Improved Union,	1 : 1	2·043	1·922	1·536	1·833	2·382	1·897	2·548	2·275	9·554	9·627	10·667	9·949
19. Union,	1 : 1	5·939	5·685	5·108	5·577	7·621	8·658	8·089	8·122	15·183	14·338	14·378	14·633
45. Stettin,	1 : 2	6·275	6·438	6·349	6·354	9·368	10·319	9·883	9·856	21·514	21·940	21·503	21·652
33. Egypt Port.,	1 : 2	13·214	15·061	14·066	14·113	27·291	28·239	27·814	27·781	52·149	52·711	50·867	51·909
5. Giant Port.,	1 : 2	22·314	23·916	24·015	23·415	35·809	47·746	52·087	45·214	99·290	109·978	99·833	103·033
12. B. & S. Eng. Port.,	1 : 2	35·699	36·055	35·436	35·730	43·744	45·316	44·154	44·404	65·069	65·768	65·342	65·393
39. Old Newark Port.,	1 : 2	109·697	112·831	111·354	111·294	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

TABLE V.—Neat Cements. Seven Days.

Variety.	Pressure, 75 Pounds Per Sq. In.		Pressure, 100 Pounds Per Sq. In.		Pressure, 200 Pounds Per Sq. In.	
	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.
4. B. & S. Eng. Port., .	. . .	. . .	. . .	. . .	. . .	. .
24. Improved Union, . .	. . .	. . .	.	. . .	. . .	. . .
15. Egypt Port., ...	. . .	. . .	. . .	. . .	. . .	. . .
20. Stettin Port., . . .	. . .	. . .	0·008	0·006	0·055	0·040
54. Old Newark Port., .	. . .	. . .	0·045	0·032	0·205	0·148
22. Union, ...	0·046	0·033	0·069	0·050	0·134	0·096
11. Anchor (Coplay), .	0·090	0·065	0·128	0·092	0·184	0·132
3. Giant Port., ...	0·126	0·091	0·084	0·060	0·371	0·267

TABLE VI.—Neat Cements. Twenty-eight Days.

Variety.	Pressure, 75 Pounds Per Sq. In.		Pressure, 100 Pounds Per Sq. In.		Pressure, 200 Pounds Per Sq In.	
	Ounces Per Surface of 1 Sq. In Per Hour.	Quarts Per Surface of 1 Sq. In. Per 24 Hours.	Ounces Per Surface of 1 Sq. In. Per Hour.	Quarts Per Surface of 1 Sq. In. Per 24 Hours.	Ounces Per Surface of 1 Sq In. Per Hour.	Quarts Per Surface of 1 Sq. In. Per 24 Hours.
7. B. & S. Eng. Port., .	. . .	. . .	. . .	. . .	. . .	. . .
23. Improved Union, .	. . .	. . .	. . .	. . .	. . .	. . .
14. Egypt Port., . . .	. . .	. . .	. . .	. . .	. . .	. . .
41. Stettin Port , . . .	. . .	. . .	. . .	. . .	. . .	. . .
6. Old Newark Port., .	. . .	. . .	. . .	. . .	. . .	. . .
21. Union, ...	. . .	. . .	. . .	. . .	. . .	. . .
2. Giant Port., ...	. . .	. . .	. . .	. . .	. . .	. . .
10. Anchor (Coplay), .	0·047	0·034	0·072	0·052	0·220	0·158

TABLE VII.—Mortars. Seven Days.

Variety.	Ratio Cement to Sand.	Pressure, 75 Pounds Per Sq. In.		Pressure, 100 Pounds Per Sq. In.		Pressure, 200 Pounds Per Sq. In.	
		Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.
9. Anchor (Coplay), . .	1 : 1	2·087	1·503	3·245	2·336	8·783	6·323
49. Stettin Port., . . .	1 : 2	2·926	2·107	4·598	3·310	14·596	10·508
42. Improved Union, . .	1 : 1	4·800	3·456	7·406	5·332	16·326	11·754
18. Union, ...	1 : 1	17·219	12·397	23·746	17·096	50·292	36·207
17. B. & S. Eng. Port., .	1 : 2	21·975	15·821	32·675	23·524	66·133	47·612
35. Giant Port., ...	1 : 2	35·616	25·641	46·169	33·239	59·571	42·888
52. Old Newark Port., .	1 : 2	43·187	31·092	69·676	50·163	. . .	. . .
13. Egypt Port., ...	1 : 2	59·097	42·546	72·998	52·554	140·661	101·263

TABLE VIII.—Mortars. Twenty-eight Days.

Variety.	Ratio Cement to Sand.	Pressure, 75 Pounds Per Sq. In.		Pressure, 100 Pounds Per Sq. In.		Pressure, 200 Pounds Per Sq. In.	
		Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quartz Per Surface of Sq. In. Per 24 Hours.	Ounces Per Surface of Sq. In. Per Hour.	Quarts Per Surface of Sq. In. Per 24 Hours.
8. Anchor (Coplay), . .	1 : 1	0·456	0·328	0·766	0·551	1·963	1·413
16. Improved Union, . .	1 : 1	0·778	0·560	0·966	0·695	4·222	3·040
19. Union, ...	1 : 1	2·367	1·704	3·447	2·482	6·210	4·471
45. Stettin, ...	1 : 2	2·696	1·941	4·183	3·012	9·189	6·616
33. Egypt Port., ...	1 : 2	5·990	4·312	11·791	8·489	22·031	15·861
5. Giant Port., ...	1 : 2	9·938	7·155	19·189	13·815	43·728	31·482
12. B. & S. Eng. Port., .	1 : 2	15·164	10·917	18·846	13·568	27·754	19·981
39. Old Newark, ...	1 : 2	47·235	34·006	. . .	. . .	. .	. . .

Analysis of Cements by Oliver Hough, B S., P.C.

	No. 2.	No. 3.	No. 4.	No. 6.	No. 5.	No 7.	No. 8.*
Portion Soluble in HCl. Silica,	13·92	16·88	21·14	20·99	10·18	24·44	16·22
Alumina,	8·52	6 92	1·02	4·12	4·55	4·69	. . .
Ferric oxide,	3·20	3·82	2·01	5·18	2·41	3·80	. . .
Phosphoric acid,	1·82	1·08	. . .	1·17	1·33	0·50	. . .
Lime,	45·07	58·40	66·04	60·75	59·91†	52·39	55·74
Magnesia,	7·86	2·06	0·47	0·41	0·60	3·47	. . .
Alkalies,	1·61	1·03	1·78	1·79	1·61	2·03	. . .
Insoluble Portion. Calcium Sulphate,	3·21	4·32	3·73	5·02	2·01	3·24	2·57
Silica,	11·33	4·99	4·36	1·45	13·39	5·17	7·35
Alumina and ferric oxide,	2·59	0·60	trace	. . .	3·70	trace	1·05
Oxide of manganese,		trace	. . .	. . .		trace	
Magnesia,	0·86	0·36	. . .	. . .	0·31	. . .	. . .
Total,	99·99	100·46	100·55	100·88	100·00	99·73	
Total silica,	25·25	21·87	25·50	22·44	23·57	29·61	23·57
Total alumina and ferric oxide,	14 31	11·34	3·03	9·30	10·66	8·49	. . .
Total magnesia,	8·72	2·42	0·47	0·41	0·91	3·47	. . .

* Uncompleted.

† By difference.

The last four tables were computed from the results as stated in the first four, on the assumption that the percolation varies directly as the diameter and inversely as the thickness. They are reduced to the basis of quarts in twenty-four hours for greater convenience in plotting the curves.

These results show that all cements are not permeable to water, at least for thicknesses of not less than three inches, while the mortars are all permeable; the amount increases with the pressure and decreases with age of specimen, but not in a direct ratio.

Large surfaces, however, are very apt to contain cracks and flaws which greatly increase the permeability. Magnesia is an undesirable constituent, as it causes expansion and ultimate crumbling or flaking. Sulphur will destroy stone or concrete. It is more serious, as it is more intimately mixed. There are colors that contain so much sulphur as to destroy concrete.* The chemical compositions of the cements submitted are given in the above table.

The diagram herewith will give a more comprehensive view of the action of these specimens under pressure. No results are plotted for the non-permeable cements.

For the purpose of comparison it may be well to add that the Board of Experts on the Washington Aqueduct Tunnel in investigating this subject, found that "a good, fair specimen of brick, * * under a pressure of water amounting to eighty pounds per square inch, for one hour, passed 23·4 cubic inches of water." During the second hour it was 21·3 cubic inches. "This is equivalent to 1·75 gallons per square foot of surface per hour, or for the whole surface of the tunnel 27,342,000 gallons per day of twenty-four hours." "Blocks of cement mortar were prepared in the proportion of one part of cement to two of sand," and after setting in water for five weeks one of them gave 2,367·8 cubic inches of water in two and one-half hours under eighty pounds pressure, "equivalent to 73·8 gallons per square foot of surface per hour—very far beyond the amount of percolation given by brick." "The sand here used was not of the very first quality, and the cement brick presented the appearance of great porosity."

Mr. Jas. B. Francis' experiments "showed that about seventeen and one-fourth gallons per square foot passed through a thickness of nearly sixteen inches of cement in

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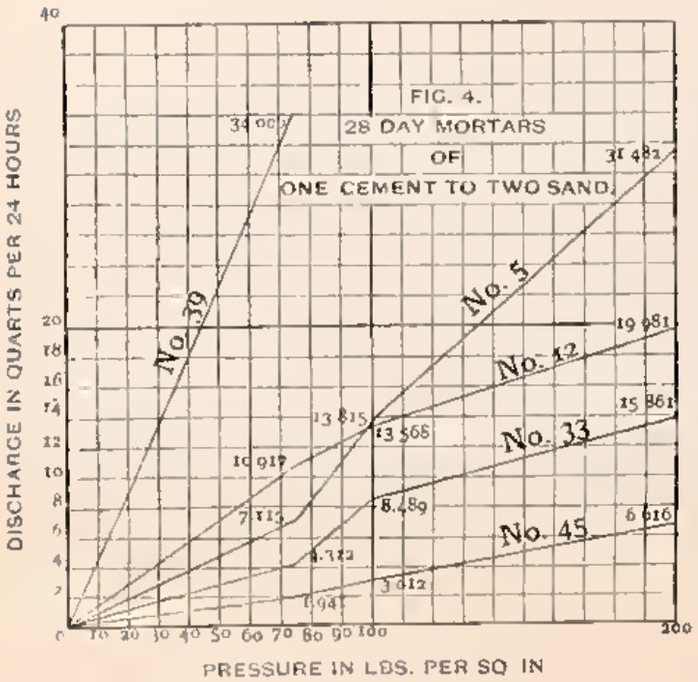
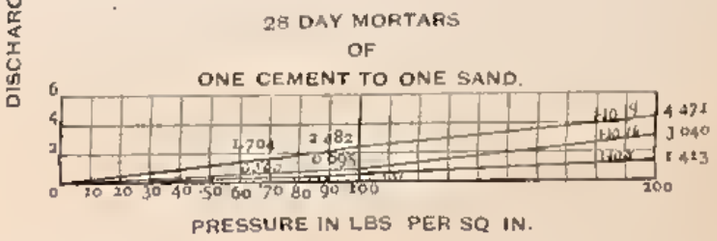
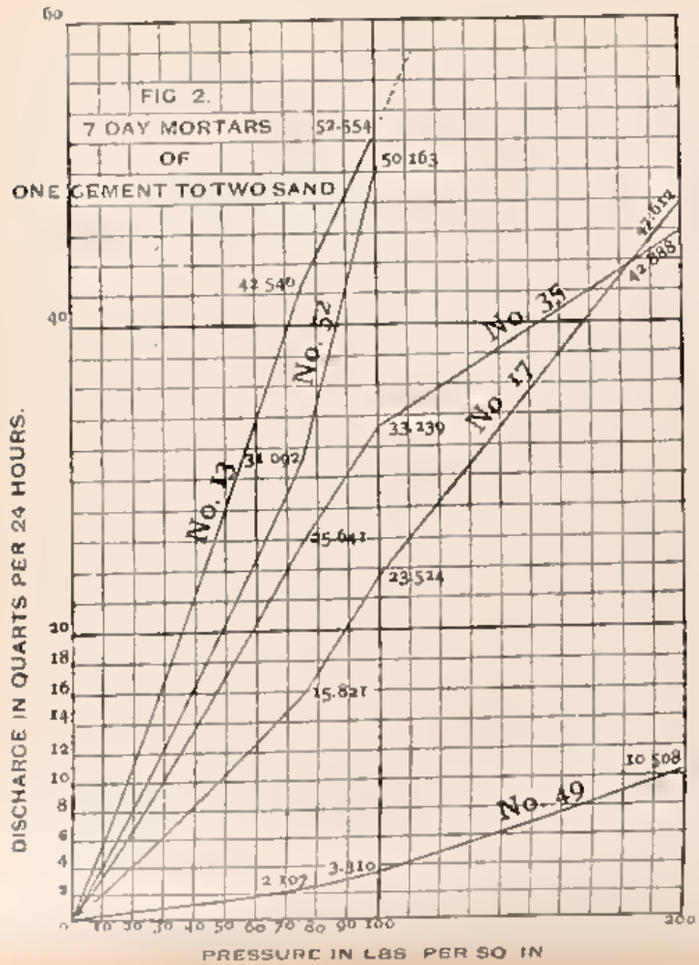
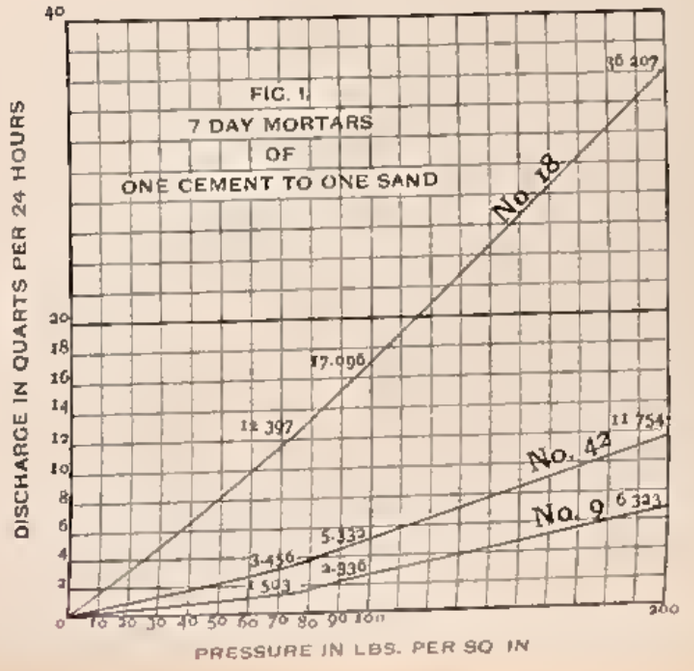
* John C. Goodridge, Jr., 113 East Twenty-fifth Street, New York.

		7 DAYS	28 DAYS
EGYPT PORT,	.	No. 13	33
OLD NEWARK PORT,		No 52	39
GIANT PORT,	.	No. 35	5
B. AND S. ENG. PORT,		No. 17	12
UNION,	. . .	No. 18	19
IMPROVED UNION,		No. 42	16
STETIN PORT,	.	No 49	45
ANCHOR COPLEY,		No. 9	8









twenty-four hours under a pressure of seventy-seven pounds per square inch." "Mr. Stauffer's experiments, made in the Dorchester Bay Tunnel, serve to throw light on the leakage through brick work. He constructed a bulkhead of brick, laid in cement, four feet thick, in a tunnel 10 x 10 feet. He found that under a pressure of seventy-two pounds per square inch the water percolated through at the rate of 120,000 gallons a day, or 1,200 gallons per square foot." "The experience on the Boston main drainage works proved that it was not practicable to build brick masonry that was water-tight under a pressure of sixty-four pounds per square foot.

"At the new Croton Reservoir, New York, water under thirty-six feet head was found to percolate through twenty-six inches of brickwork and four feet of concrete."*

When water was let into the Vanne Aqueduct in the spring of 1869 the inspector, M. Belgrand, certified that "*Impermeability appeared complete.*"

This conduit is built for miles of béton-aggloméré, composed of sand and cement. The pipe is circular, six and one-half feet in interior diameter, with a thickness of twelve inches at the sides at the water surface, and nine inches at top.

These results show a great range in the amount of percolation, due mainly to the size and character of the ingredients and the manner of mixing.

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* *Vide Report on Washington Aqueduct Tunnel,* p. 21. House of Rep. Fiftieth Congress, Second Sess. Report No. 4,142.